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Award Number: W81XWH-10-1-0870

TITLE: Advanced Prosthetic Gait Training Tool

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REPORT DATE: September 2011

TYPE OF REPORT: Final

PREPARED FOR: U.S. Army Medical Research and Materiel Command  
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for Public Release;  
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REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
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1. REPORT DATE September 2011		2. REPORT TYPE Final		3. DATES COVERED 20 August 2010 – 19 August 2011	
4. TITLE AND SUBTITLE  Advanced Prosthetic Gait Training Tool				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER W81XWH-10-1-0870	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)  Rajankumar Bhatt, John Yack, Salam Rahmatalla, Jason Wilken, Rich Degenhardt, and Karim Abdel- Malek  E-Mail: amalek@engineering.uiowa.edu				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  The University of Iowa Iowa City, IA 52242				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Medical Research and Materiel Command Fort Detrick, Maryland 21702-5012				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for Public Release; Distribution Unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The objective of our study is to produce a computer-based Advanced Prosthetic Gait Training Tool to aid in the training of clinicians at military treatment facilities providing care for wounded service members. In Year 1 of the effort, significant work was completed at the University of Iowa Center for Computer-Aided Design (CCAD), the University of Iowa Orthopedic Gait Analysis Laboratory (OGAL), and the Military Performance Laboratory (MPL). A representative set of motion capture sequences was provided by MPL to CCAD and OGAL. CCAD's work focused on imposing these sequences on the Santos™ digital human avatar. An initial user interface for the training application was also developed. These data were then provided to researchers from OGAL and MPL to support an assessment of the ability of trained clinicians to observe and accurately identify gait deviations in the target environment. Researchers at OGAL also embarked on a program to develop a web-based questionnaire to identify the sensitivity of gait experts to detect variations in gait using the Santos software. The information gathered from this approach during the next phase will be used to identify a set of gait profiles and to develop the training and evaluation questionnaire. The current state of the training tool thus demonstrates the ability of the three different groups to work together to accomplish the ultimate objective this multi-year project.					
15. SUBJECT TERMS None provided.					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			USAMRMC
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# Advanced Prosthetic Gait Training Tool

## INTRODUCTION:

The objective of our study is to produce a computer-based Advanced Prosthetic Gait Training Tool to aid in professional development for clinicians and prosthetists at military treatment facilities providing care for wounded service members. The effort will ultimately provide practitioners at all clinics and hospitals with access to advanced, computer-based gait analysis tools that are currently available at only a few state-of-the-art gait laboratories. The tool will aid in the training of service providers, ultimately improving the level of care they provide to wounded veterans. Due to the wide variety of injuries suffered by military personnel and wide ranging medical interventions employed to improve the standard of living for patients, it is very challenging to expose medical practitioners to a comprehensive set of human subjects to support their training in gait analysis. Under this effort, an extensive set of archived motion capture data representing gait patterns for wounded service members with varying challenges will be harvested from the Military Performance Laboratory at the Center for the Intrepid at Brooke Army Medical Center in San Antonio. To ensure confidentiality for these service members, the gait patterns will be imposed on a digital human model, referred to as Santos<sup>TM</sup>. This computer-based model provides additional benefit to trainees, allowing for the repeated virtual playback of motion capture sequences that can be viewed from any angle. Options will also be provided to allow trainees to view clothed or unclothed avatars, stick figures, or even skeletal models to support their analyses. The system will also allow trainees to isolate specific parts of the anatomical model for detailed analysis. Trainees will enter their assessments of observed gait deviations, which will be scored against standard measures prepared by experts in the field. Based on the accuracy of the trainees' responses, the system will provide remediation to the trainees. When fully developed, this system will provide a comprehensive training experience, allowing practitioners to benefit from a broad array of patient data previously collected by the US Army, thus bridging a critical gap in current medical training practices. The system will be developed to accommodate additional sequences captured over time, thus offering an extensible, distributable, and sustainable training library.

In Year 1 of the effort, significant work was completed at the University of Iowa Center for Computer-Aided Design (CCAD), the University of Iowa Orthopedic Gait Analysis Laboratory (OGAL), and the Military Performance Laboratory (MPL). A representative set of motion capture sequences was provided by MPL to CCAD and OGAL. CCAD's work focused on imposing these sequences on the Santos digital human avatar. An initial user interface for the training application was also developed. These data were then provided to researchers from OGAL and MPL to support an assessment of the ability of trained clinicians to observe and accurately identify gait deviations in the target environment. Researchers at OGAL also embarked on a program to develop a web-based questionnaire using the Santos software. This questionnaire will be sent to experts in the field of gait analysis. The primary goal of the questionnaire is to identify the sensitivity of gait experts to detect variations in gait of different severity levels in the patients. In addition, the differences in ability to detect variations in gait conditions for skinned avatar vs. line-skeletal avatar, concurrent (side-by-side) image representation vs. consecutive (one after the other) image representation, and image vs. movie representation was also studied. The information gathered from this approach will be used to identify a set of gait profiles and to develop the training and evaluation questionnaire.

## BODY:

The current base effort should demonstrate the feasibility of developing a curriculum centered around motion-capture data collected at MPL within the Santos environment and subsequently, demonstrate the feasibility of the effort to USAMRMC. The three main components of the project are: 1) motion capture investigations; 2) gait deviation ratings; and 3) software design. Each of these components required two more teams to work together to accomplish the task. Initial motion-capture gait data, in C3D format, were received from MPL and were used as a proof of concept in animating a computer human model Santos. Visual 3D software (c-motion) was used to create a kinematic model, which was used to calculate the joint center profiles based on the received marker data. The Cartesian marker and joint-center positions were used inside an in-house inverse kinematics algorithm to transform the human motion from the Cartesian space to the joint space. The resulting joint angle profiles were then used to animate Santos. Several files were successfully processed and were used in the subsequent steps. There were some

difficulties in defining the upper-body joint centers due to the inconsistency between the received marker data and the Santos marker protocol; nevertheless, this problem was circumvented at this time using virtual markers. Additional work has been conducted to investigate the accuracy of the resulting motion inside Santos. While the latter process was acceptable, still, this initial investigation has opened the door for promising improvement in this data transformation. A very simple and intuitive interface, as shown in Figure 1, was designed to display the motions resulting from this motion capture data on Santos. The interface allows user to play a pre-processed motion profile on the Santos avatar in the digital environment. An online assessment tool was developed using Santos images, converted from these motion profiles provided by MPL. The outcome of this assessment will enable us to set the parameters on the spectrum of gait deviations that can realistically be observed. By having a baseline of what is possible to detect, we will also be able to use this information in determining if the focus of attention of the observer is appropriate. Each of these three main components is discussed in detail in the next section.

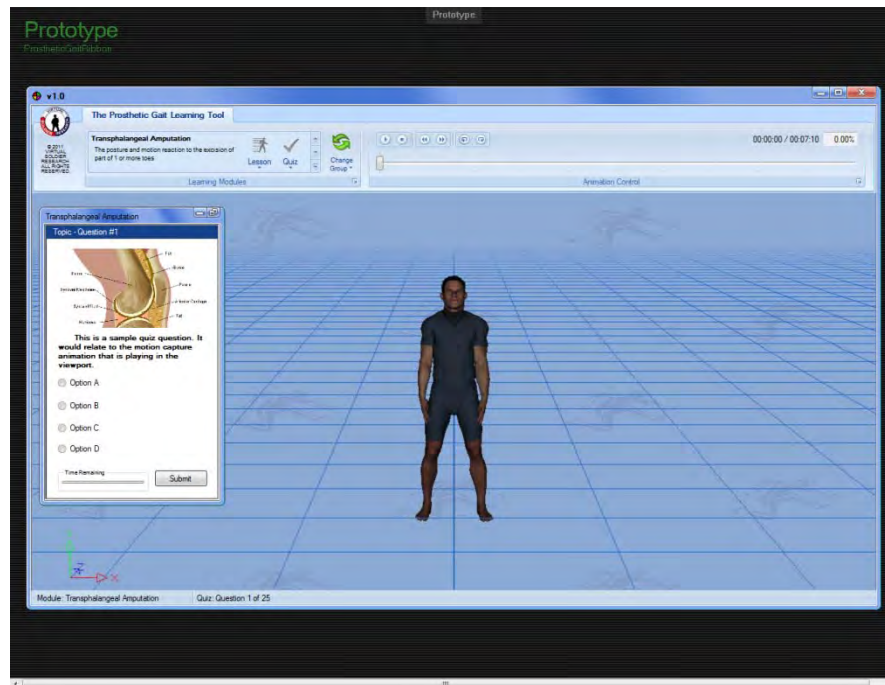


Figure 1 – Initial prototype design of the graphical user interface of the Prosthetic Gait training tool.

## Motion Capture

Human gait test data was obtained for a control participant, a trans-tibial amputee, and a trans-femoral amputee. The following steps were taken to translate the data from motion capture to the Santos model.

1. Visual 3D joint centers exported for major joints
  - a. Requires export template for batch processing
  - b. For Visual 3D visualization, upper-body model was adjusted to include head and thorax
2. Virtual points exported for additional joint centers
  - a. Requires landmark definitions and export template
3. Matlab processing to compile the data and calculate final joint centers
4. In-house inverse kinematics processing

## MARKER PLACEMENT PROTOCOL

Based upon the data received, the marker data that was available is summarized in Table 1 through Table 4.

Table 1: Head markers (4)

NAME	DESCRIPTION
RFHD, LFHD	Right front head, Left front head
RBHD, LBHD	Right back head, Left back head

Table 2: Torso markers (18)

NAME	DESCRIPTION
C7	C7 spinous process
RBack	Placed above the medial border of the scapula on the level of T3
T7	T7 spinous process
CLAV	Placed in the center of the clavicles
RCLAV, LCLAV	Placed over each clavical, midway between manubrium and acromion
STRN	Xiphoid process
T10	T10 spinous process
T12	T12 spinous process, follow rib cage back to spine to determine location
LBack	Midway between the lateral edge of the torso and the T12 spinous process
L3	L3 spinous process
S1	Superior on the sacrum (S1 process)
RPSI, LPSI	Posterior Superior Iliac Spine location
RASI, LASI	Placed bilaterally over Anterior Superior Iliac Spines
RHip, LHip	Placed bilaterally over greater trochanter

Table 3: Arm markers (22)

NAME	DESCRIPTION
RSHO, LSHO	Placed over most superior point of the acromion process (shoulder)
RSHOF, LSHOF	Glenohumeral markers on anterior of shoulder, placed midway between top lateral edge of acromion and axilla
RSHOB, LSHOB	Glenohumeral markers on posterior of shoulder, placed midway between top lateral edge of acromion and axilla
RProxA, LProxA	On the arm between the shoulder and elbow
RElbow, LElbow	Placed over lateral epicondyle of humerus
RElbowIN, LElbowIN	Placed over medial epicondyle of humerus
RDistA, LDistA	On the forearm between the elbow and wrist
RWRA, LWRA	Placed over wrist radial styloid process (thumb-side)
RWRB, LWRB	Placed over wrist ulnar styloid process (pinky-side)
RHandA, LHandA	Placed over 1 <sup>st</sup> metacarpal head
RHandB, LHandB	Placed over distal end of middle phalange as end effector

Table 4: Leg Markers (18)

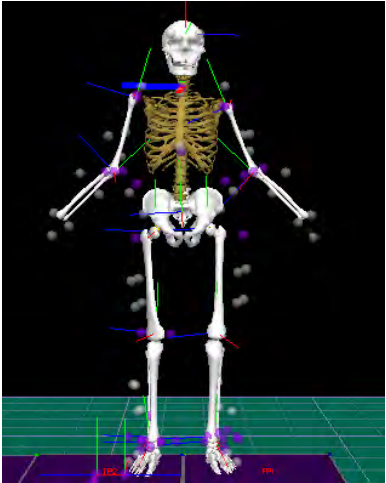
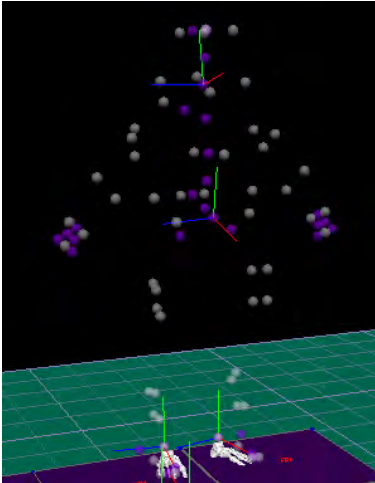
NAME	DESCRIPTION
RProxL, LProxL	On the leg between the hip and knee
RKnee, LKnee	Placed over lateral condyle of femur
RKneeIN, LKneeIN	Placed over medial condyle of femur
RDistL, LDistL	On the shank between the knee and ankle

RAnkle, LAnkle	Placed over lateral malleolus of fibula
RAnkleIN, LAnkleIN	Placed over medial malleolus of tibia
RHeel, LHeel	Placed on the calcaneus
RMidFoot, LMidFoot	Midpoint along 5 <sup>th</sup> metatarsal (lateral foot)
RToe, LToe	Placed over head of 1 <sup>st</sup> metatarsal (just proximal to 'big toe')

### **JOINT CENTERS**

There was inconsistency between the received marker protocol and the Santos marker protocol, as the latter has a high-degree-of-freedom detailed skeleton. In order to obtain the required joint centers for Santos, the Visual 3D model was used for major joints, and in some cases virtual joints were created to adhere to the Santos model. The Santos model requires the joint center protocol shown in Table 5.

Table 5: Joint center processing methods-

Joint Centers from Visual 3D model		Left Hip		Spine 1
		Left Knee		Spine 2
		Left Ankle		Spine 3
		Left Shoulder		Spine 4
		Left Elbow		Spine Root
		Left Wrist		Left Hand A
		Right Hip		Left Hand B
		Right Knee		Left Toe
		Right Ankle		Right Hand A
		Right Shoulder		Right Hand B
		Right Elbow		Right Toe
		Right Wrist		Upper Neck
				Lower Neck
				Head Right
				Right Clavicle
				Left Clavicle
				Head Center

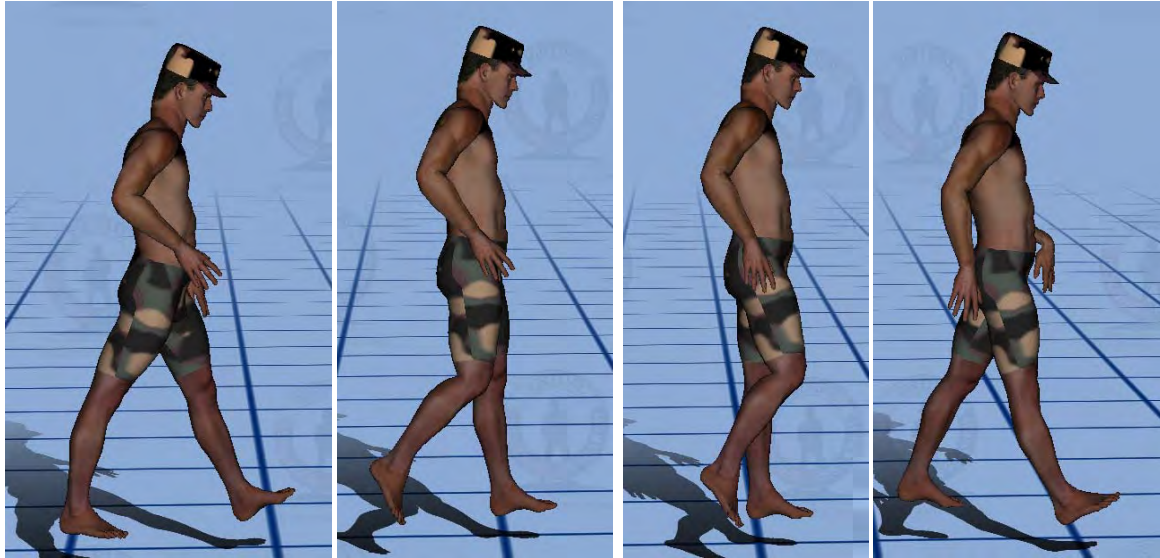
After utilizing the Visual 3D joint centers and creating landmarks for additional joint centers, the joint files were processed in Matlab to compile the joint centers and calculate any remaining joint centers. Then the in-house inverse kinematics algorithm was used to produce a Santos animation.

## ***VISUALIZATION OF THE PROFILES***

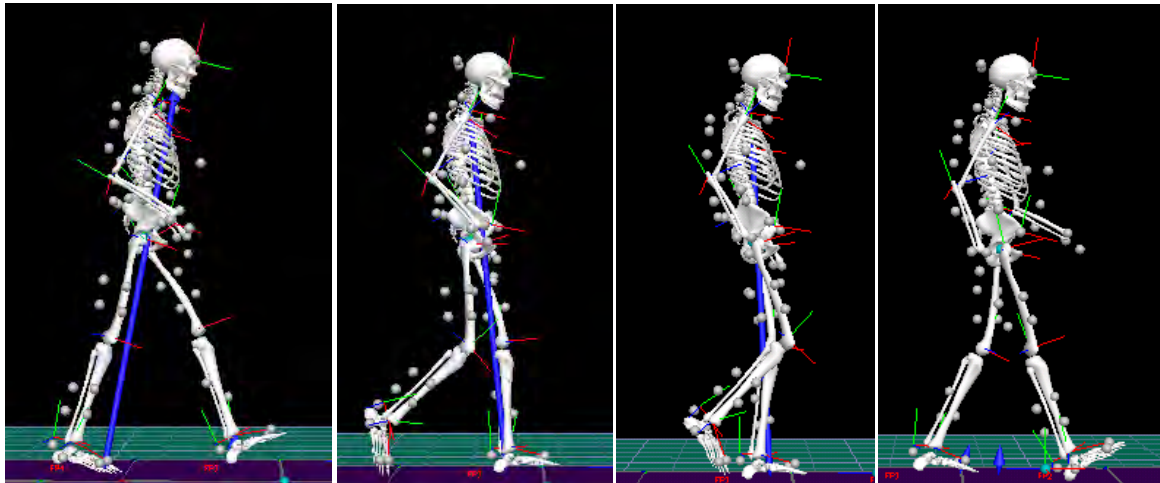
Subjective analysis was conducted on selected key frames from the gait cycle using Santos and Visual 3D software as shown in the following figures.

### Trans-femoral

#### ***Inverse Kinematics***



#### ***Visual 3D***



LHS

RTO

MS

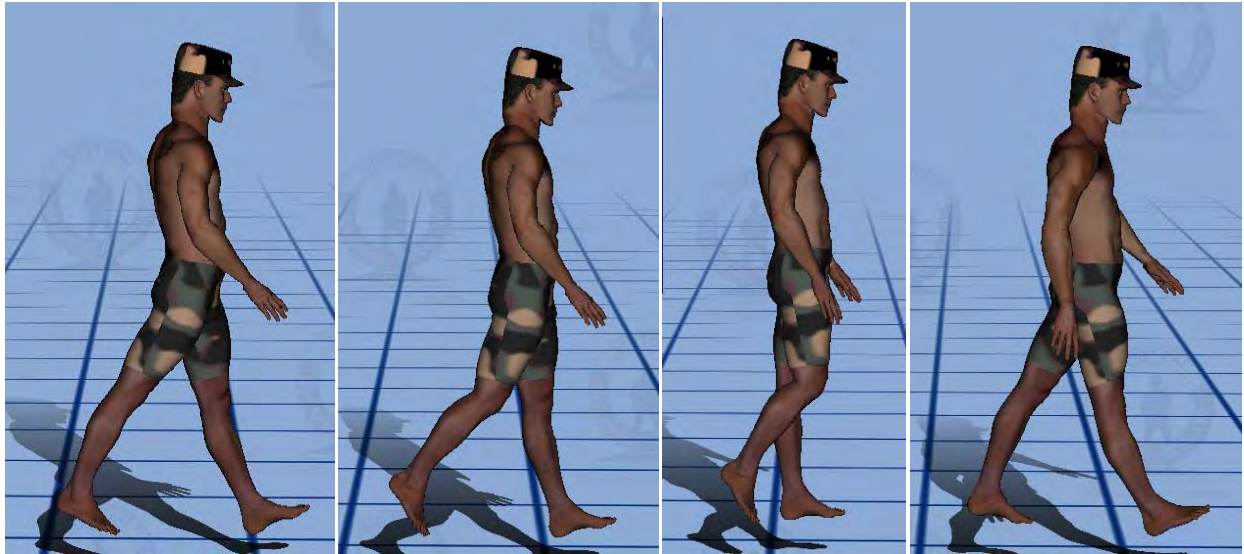
RHS

Figure 2 – Comparison between the Visual 3D model and Santos inverse kinematics for trans-femoral data.

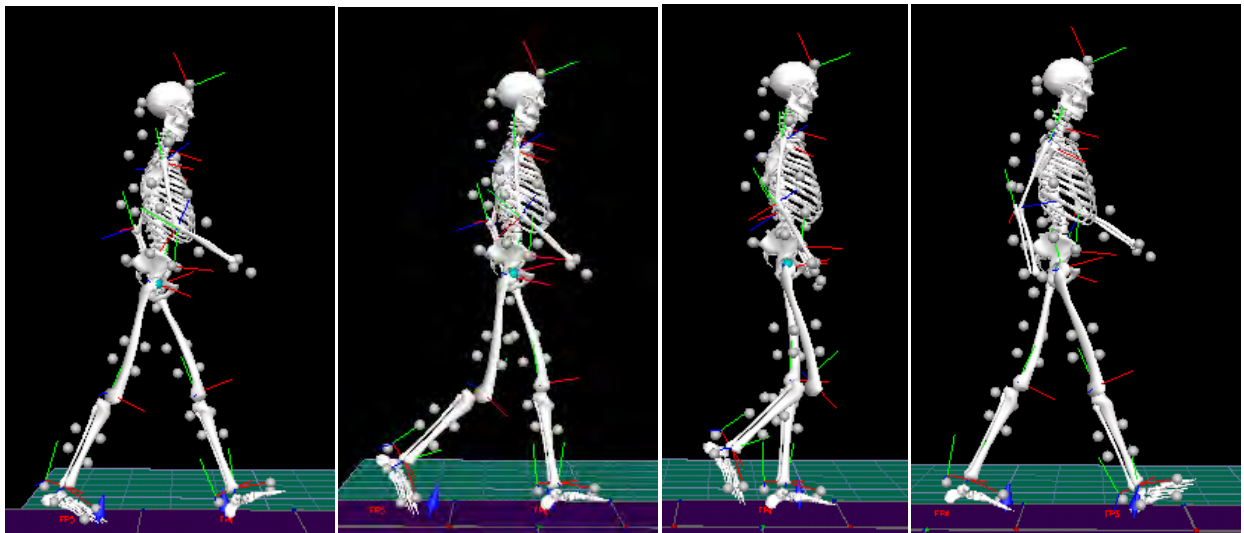


## Trans-tibial

### *Inverse Kinematics*



### *Visual 3D*



LHS

RTO

MS

RHS

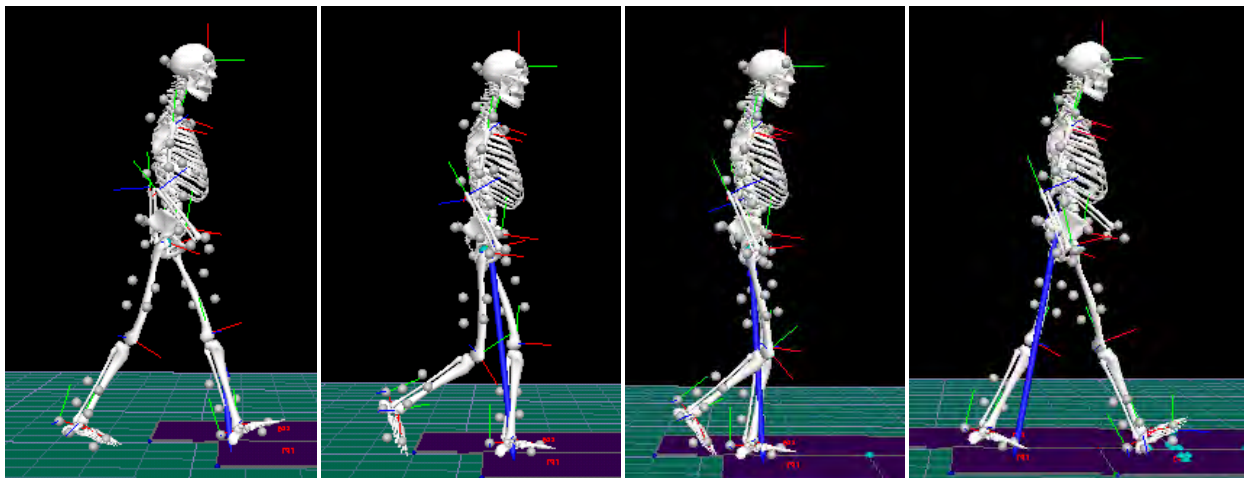
Figure 3 – Comparison between the Visual 3D model and Santos inverse kinematics for trans-tibial data.

Control

***Inverse Kinematics***



***Visual 3D***



LHS

RTO

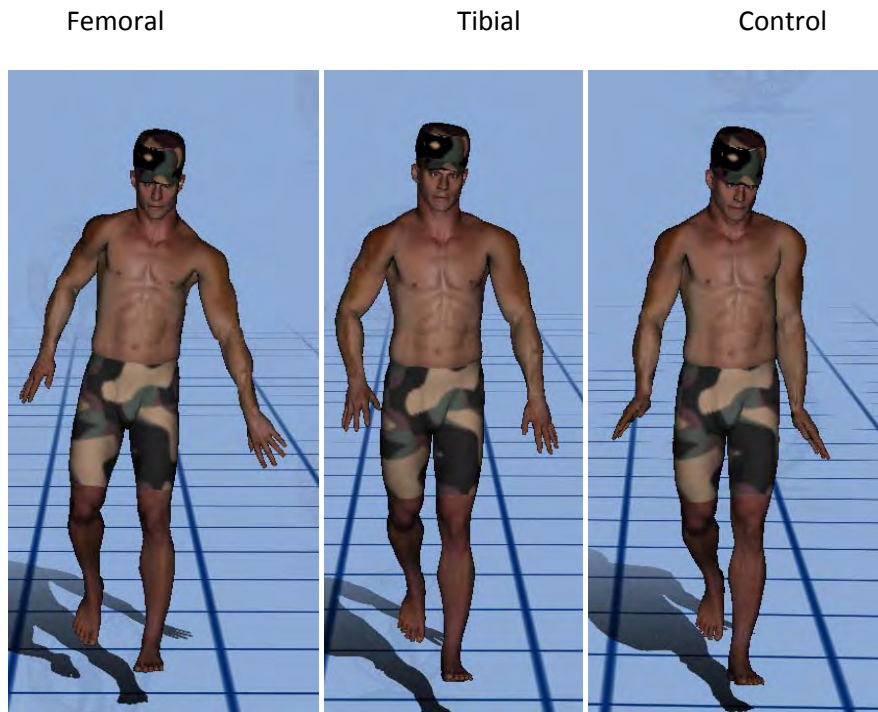
MS

RHS

Figure 4 – Comparison between the Visual 3D model and Santos inverse kinematics for control data.

Frontal View at Middle Stance

***Inverse Kinematics***



***Visual 3D***

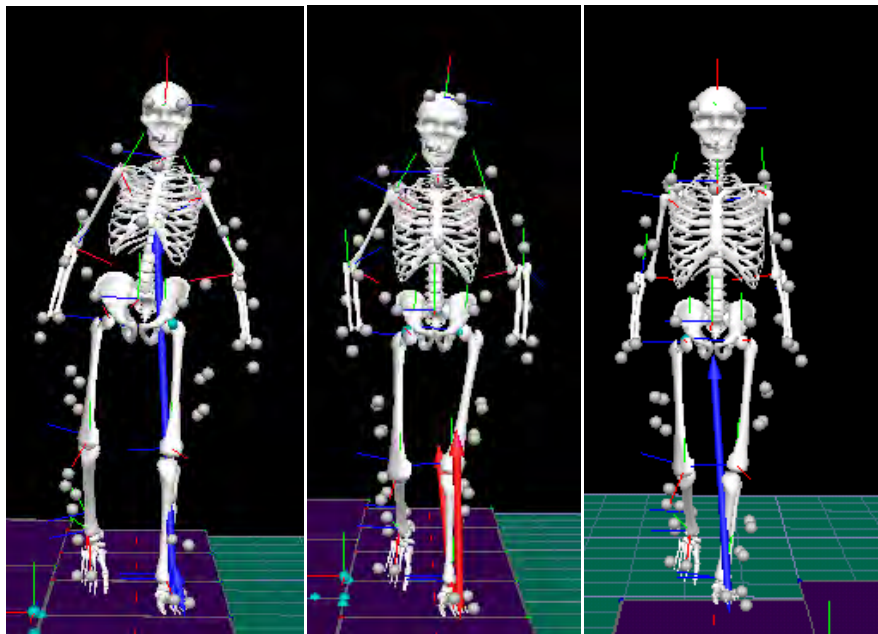


Figure 5 – Comparison between the Visual 3D model and Santos inverse kinematics at the middle stance keyframe for trans-femoral, trans-tibial, and control data.

## Gait Deviation Ratings

After surveying the literature, it was determined that there was a need to develop a way of assessing the sensitivity of observers to detect different representations of human walking. Initial discussions determined the variety of presentation features that might be included. These were mocked-up, reviewed, and prioritized by the OGAL team. It was decided to initially focus on the presentation order (side-by-side or sequential) and the form of the presentation (stick figure or avatar). Several online environments were tested, and a decision was made to use Qualtrics. An online assessment tool was developed using Santos images, converted from the MPL dataset. The outcome of this assessment will enable us to set the parameters on the spectrum of gait deviations that can realistically be observed. By having a baseline of what is possible to detect, we will also be able to use this information in determining if the focus of attention of the observer is appropriate.

A number of strategies for training individuals to detect gait deviations have been explored. The traditional approaches have used a system in which the observer looks at the motion of each segment, in isolation, and then attempts to integrate these observations. The unique approach for resending gait in this project offers the possibility to generate a systems approach. In this approach, deviations in one area will be linked to associated deviations in other areas so the inherent interdependencies of the closed-chain, kinematically linked system becomes apparent and is part of the learning process. In this way we believe that the observer can be trained to detect pattern differences. We believe that by thinking about the associated changes that are occurring, the clinician will be better able to uncover the possible underlying etiology of the gait deviation.

## Software Design

After evaluating the objectives of the prosthetic gait software, a few fundamental design goals emerged. First and foremost, the interface needed to be clean and intuitive. Because this is educational software, it is important that the interface does not present a steep learning curve to the user. Ideally, the user should know how to operate almost every aspect of the application after only a few minutes of use. To better accomplish this goal, a graphical user interface was designed and documented. Using this design, the interface was prototyped based around the technologies that would be used for development. Because the application wouldn't have a need for any nested menu systems, the design was simplified such that any function would only be one or two clicks away. Figure 1 shows the initial prototype of the interface.

Another goal that emerged during the initial software evaluation was to reduce the size and dependencies of the project. Because this application only needs a small percentage of features from the Santos software package, it should be possible to extract only the functionality that will be used. Trimming down this extra code will occur at the base layer of the application. The diagram depicting the architecture of the tool is shown in **Error! Reference source not found.** For example, the main window within the prosthetic gait software only uses the core from the Santos project, omitting other complex systems. This results in a quicker build time and less memory usage at runtime, and also allows the reduced functionality to be exposed through a simpler interface.

When deciding which tools to use for project development, the opportunity arose to move this project to the most recent suite of Microsoft tools (Visual Studio 2010). This became a primary project goal because it was important that the application utilized a few of the new features Microsoft has incorporated over the last five years. The two main new components that were implemented were the Ribbon interface and the WPF application structure. Although there was a learning curve involved in developing around these new components, they allowed for a more modern and maintainable approach to the Prosthetic Gait application.

The following screens show the current status of the prosthetic gait application. Every function within the application can be accessed with minimal navigation. The first two screens as shown in **Error! Reference source not found.** and **Error! Reference source not found.** displays the two main tab layouts within the Ribbon menu system. As the software becomes more sophisticated, additional tabbed Ribbon groups can be added, without having to continually nest the features.



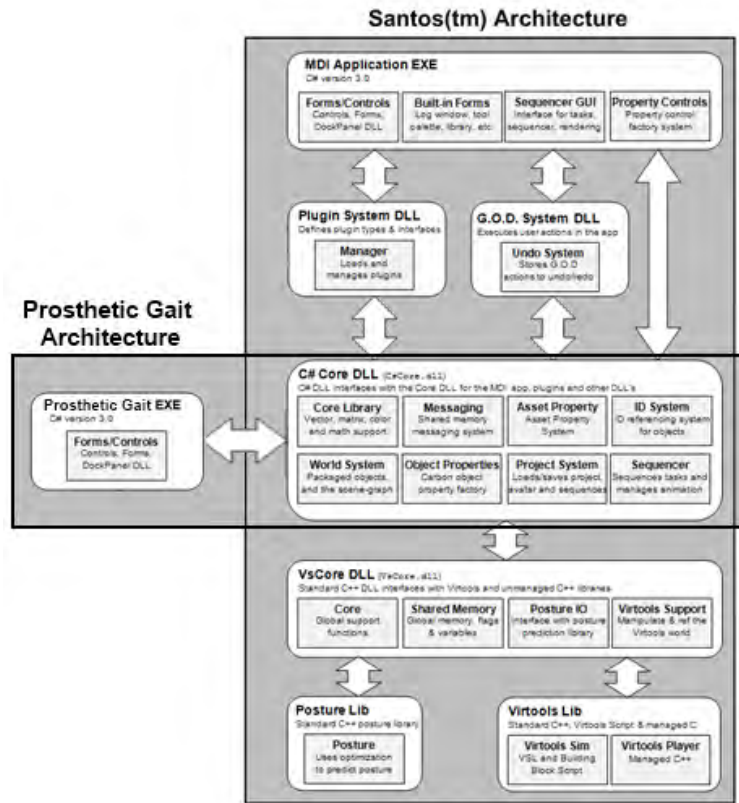


Figure 6 – Prosthetic Gait training tool software architecture.

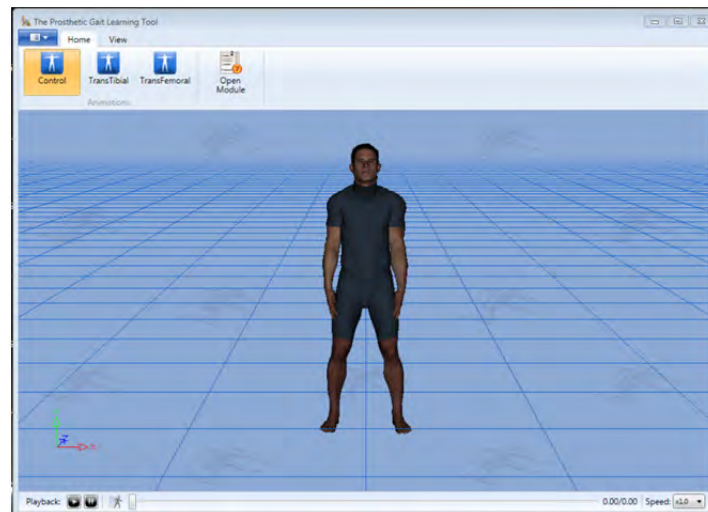


Figure 7 – Default screen for the home tab.

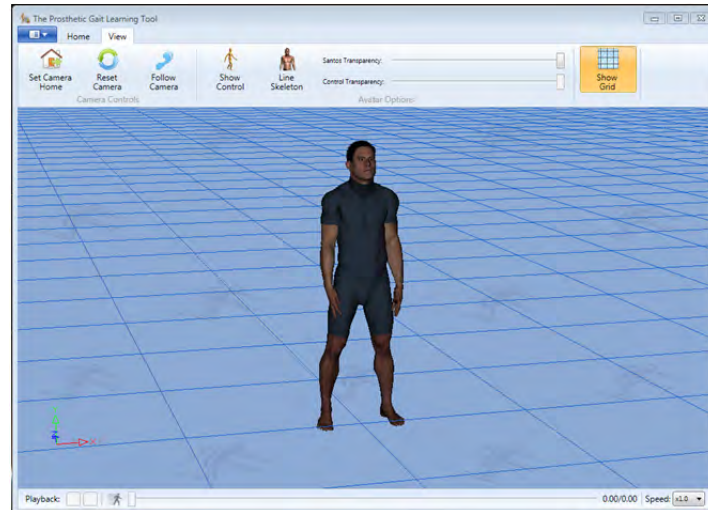


Figure 8 – Default screen for the view tab.

Figure 9 shows how simple it is to select and play an animation on the avatar. Once the motion has been selected via the respective toggle button, the playback controls become active and the animation can be viewed. The user can also rotate the camera, zoom in at any specific point, or view line skeletal vs. skinned avatar while the motion is being played.

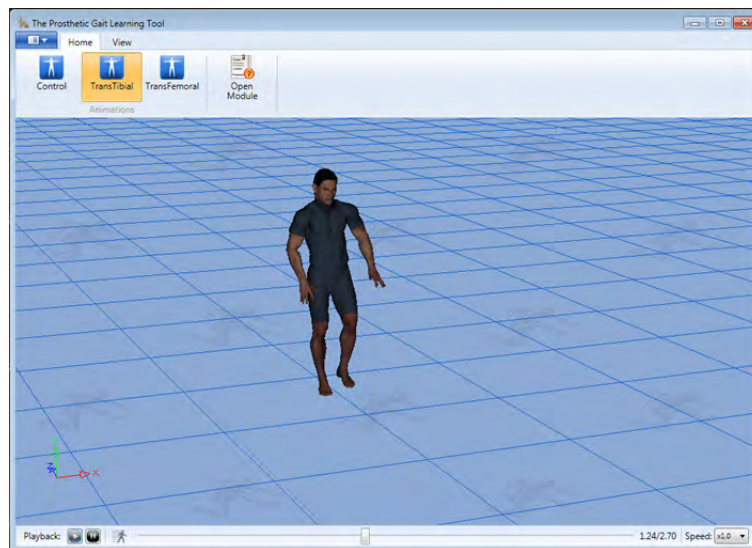


Figure 9 – Selecting and playing trans-tibial motion.

Figure 10 and Figure 11 show the ghosting and transparency features. The ghosting feature in Figure 10 allows the user to compare any prosthetic animation simultaneously with the control animation. The transparency feature allows for an easier comparison between animations, or for complete viewing of the line skeleton.

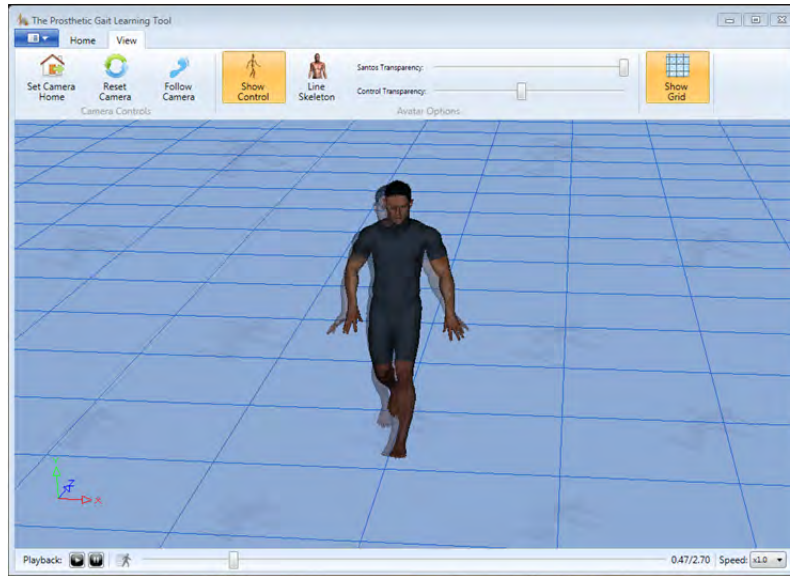


Figure 10 – Animation ghosting with the control animation, the control avatar is set to 50 percent transparency.

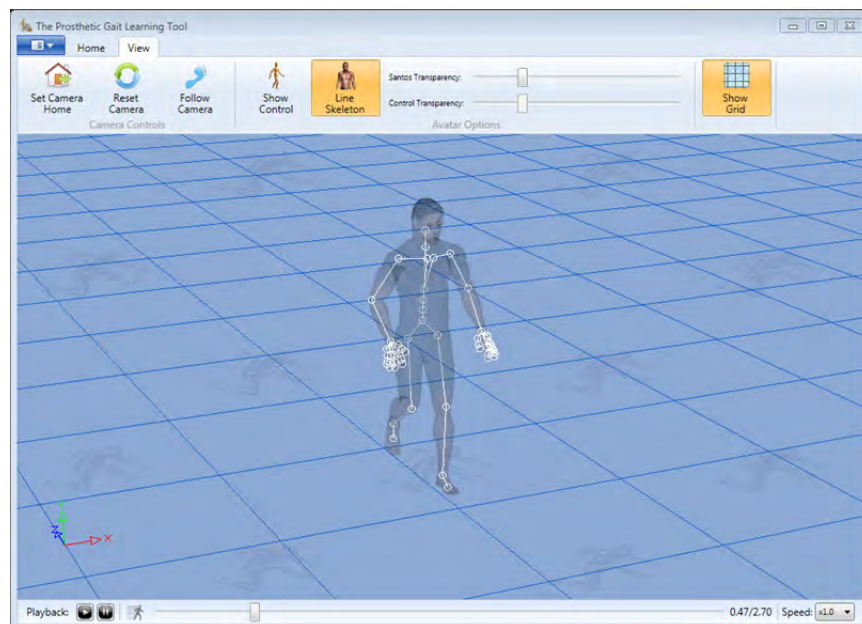


Figure 11 –Transparent Santos with visible line skeleton.

Because manipulating the scene camera is crucial to observing the animation, a set of camera controls was added. In addition to the simple mouse navigation control scheme, the user can also set the camera to follow mode or set a home location for the camera. Figure 12 shows the animation running with the follow camera enabled. The avatar will stay centered in the scene as the application plays.

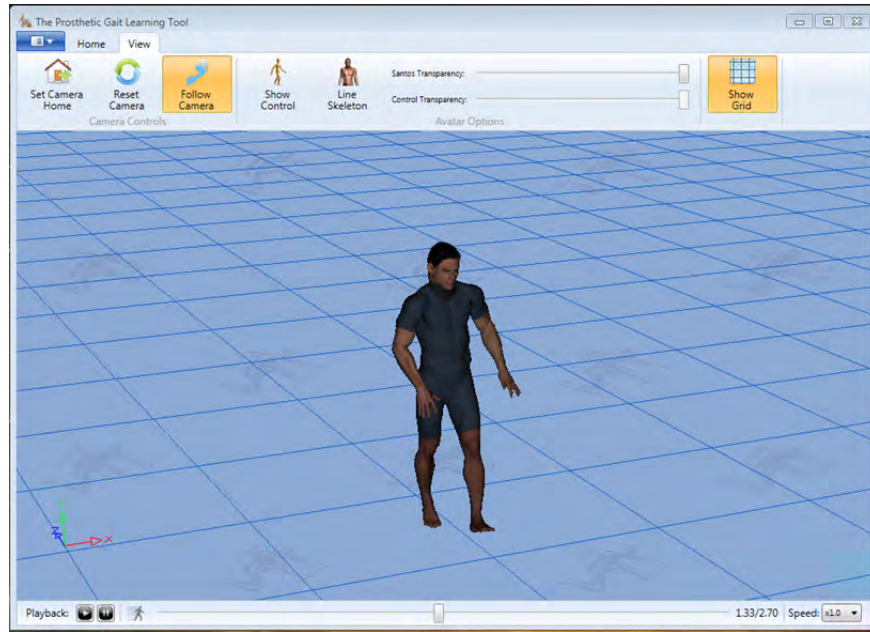


Figure 12 – The follow camera keeping the animation centered while playing.

Figure 13 and Figure 14 show the basic layout of the quiz/tutorial control. This control displays an XML file in the form of a tutorial and quiz set for a specific animation. If an animation is selected, clicking the open module button will open up the learning module for that specific animation. Once a quiz or tutorial is selected from this module, the user can navigate through the various pages in a browser style window.

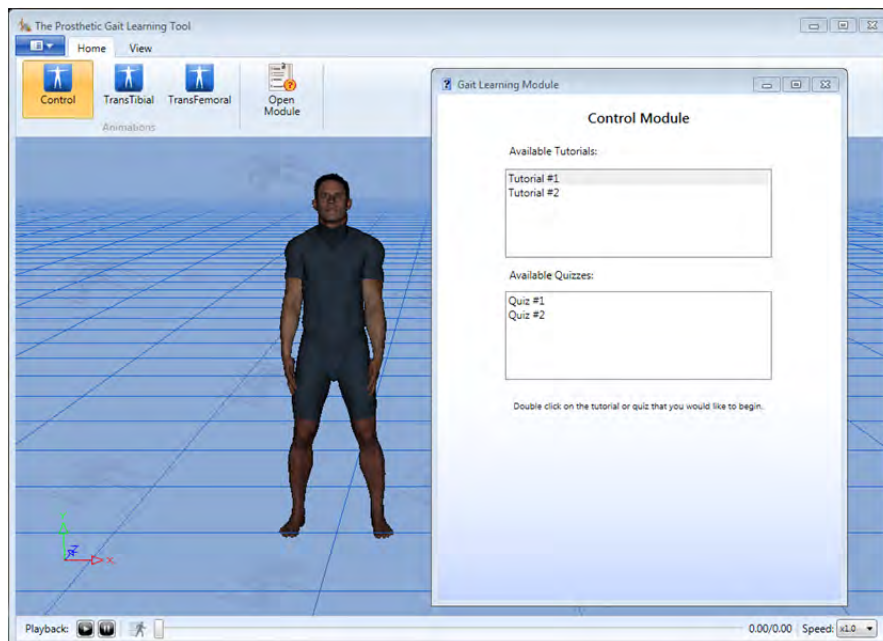


Figure 13 – The control animation learning module.



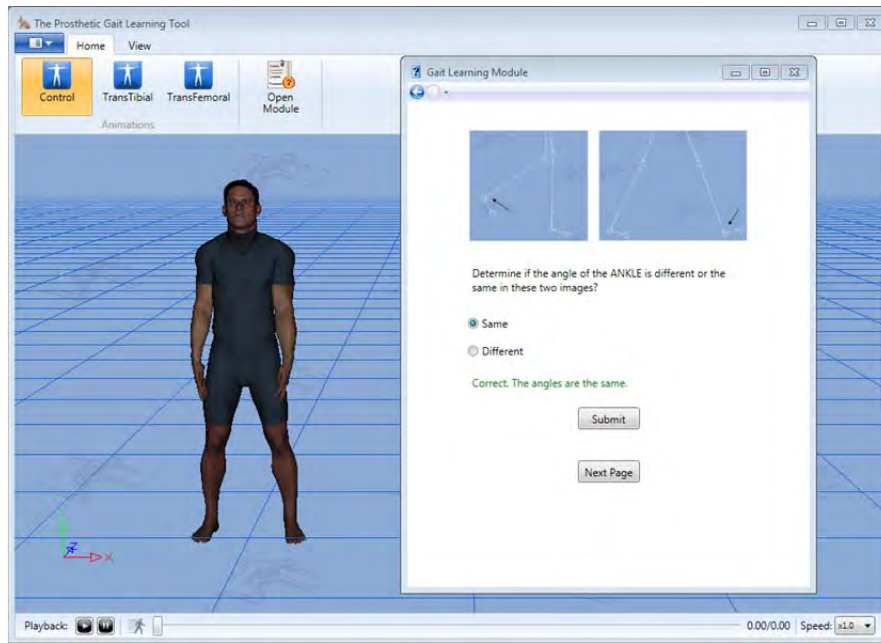


Figure 14 – A sample question from a module tutorial.

## Discussion

The fidelity of the Santos model was assessed by OGAL using sample gait trials from MPL. These samples were assessed in both the original capture system (Visual 3D) and in Santos. Differences in model presentations were noted and communicated by OGAL to both MPL and VSR. The main problem in translating the images appeared to be with the definition of some of the joint angles. Once these were corrected, samples of amputee walking patterns from MPL were translated into the Santos model. The fidelity of the model was once again verified relative to the original representation. The feasibility of using the Santos model to represent observable differences in pathological gait was substantiated by having individuals with different backgrounds and levels of expertise judge the existence of pathology (not necessarily the specific gait deviation). In addition, some abnormality in motion was due to the fact that upper-body Visual 3D model requires subject specific refinement. Resulting inaccuracy in the current upper-body model has resulted in abnormal motion in the shoulder, elbow, and trunk, which resulted in some instances of unrealistic upper-body motion. Some abnormalities in the motion can also be due to the error in joint center translation from Visual 3D to the Santos model. While some of the issues have been addressed in the current version of the software, additional steps can be taken to improve the accuracy of the playback. While the current Santos skeletal model has shown acceptable results, a more detailed and accurate biomechanical model is needed. Refine joint center calculations in Visual 3D or standardize with Matlab for efficient processing.

The current application shows how the 3D environment and core functionality from the Santos software can be applied to a more tailored learning experience. More specifically, the application shows the potential of using Santos for an observation-based learning and quizzing tool. In order to achieve this degree of functionality, a few challenges had to be overcome in the development process. The biggest and most time-consuming challenge was porting the viewport into a windows presentation environment and bringing only the necessary features along with it.

This process involved transforming the dockable form version of the viewport from the Santos software into an independent windows control for the prosthetic gait application. Changing the viewport at such a base level required not only an overhaul of the viewport properties, but also an overhaul of how the viewport would be displayed within an application window. Once this was done, the original playback and camera controls also had to be ported over and placed into the new interface. Although it was a time-consuming process, the port of the viewport was very successful.

Another interesting challenge was planning out how to execute an XML-based quiz and tutorial tool. Making these learning modules XML-based allows for a much simpler creation and editing process. The challenge was transforming an XML file into a navigation-based set of pages with functional interface elements. Because the exact nature of the quizzes and tutorials to be used in the software was unknown during development, a very open-ended approach needed to be used while designing the logic behind these XML files.

Once the core features within the software had been completed to the point at which they were functional, they needed to be tied together. This meant that within the software, the animation needed to be tied to its module along with its respective interface element. Although that did not seem too complex initially, a fairly intricate data structure needed to be set up. This data structure needed to ensure that the interface layer could efficiently communicate with the functional layer, all of which was tied together in the code (XAML) front end.

Despite the challenges faced during development, the software stands as proof that it is possible to tailor the larger Santos software in a more specific direction. The next phase, from a development standpoint, will be to hopefully use a more specific set of requirements to continue to refine and expand the software.

## **KEY RESEARCH ACCOMPLISHMENTS:**

- A new intuitive software tool developed in Visual Studio 2010 with the ability to
  - Play motion capture files
  - Change camera views to focus on a particular area or view motion from a particular angle
  - Switch between line-skeleton and skinned avatar views
  - Display training questionnaire
  - View two profiles simultaneously (using ghosting feature) to understand subtle differences in motion of various joints for different medical conditions
- Development of a web-based assessment that will be used to
  - Document the sensitivity of individuals to detect different kinematics during gait
  - Identify the extent to which the format of the presentation (stick-figure or avatar) affects discrimination
  - Determine how the relative comparisons of motion data are affected by presentation order (side-by-side vs. sequential)

## **REPORTABLE OUTCOMES:**

The current base effort served to demonstrate the feasibility of developing a curriculum centered on motion-capture data collected at MPL within the Santos environment. Since the effort focused on demonstrating that each of the three research groups involved can work together to produce a useful tool, no substantial reportable outcomes (publications) have been produced. However, many interesting research problems have been identified with potential for publications.

## **CONCLUSION:**

Substantial progress has been achieved in the current base effort under this project. A working graphical user interface has been developed that can show processed motion capture profiles from MPL and can display questionnaires developed by OGAL to serve as a training software. In addition, an online assessment tool was developed using Santos images converted from the MPL motion capture profiles. This questionnaire will help us identify baseline parameters on the spectrum of gait deviations that can realistically be observed. By having a baseline of what is possible to detect, we will also be able to use this information in determining if the focus of attention of the observer is appropriate while further developing the training tool. When the tool is fully developed, it will provide practitioners at all clinics and hospitals with access to advanced, computer-based gait analysis tools that are currently available at only a few state-of-the-art gait laboratories. The tool can also benefit from substantial research in predicting the motion profiles for normal humans being undertaken at The University of Iowa. The tool

will aid in the training of service providers, ultimately improving the level of care they provide to wounded veterans. This system will, thus, provide a comprehensive training experience, allowing practitioners to benefit from a broad array of patient data previously collected by the US Army, thus bridging a critical gap in current medical training practices. The system will be developed to accommodate additional sequences captured over time, thus offering an extensible, distributable, and sustainable training library.

## **References:**

There are no references for this report.

## **Appendices:**

There are no appendices for this report.